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Patentanmeldung Nr. Patent application No. Demande de brevet n°

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Koninklijke Philips Electronics N.V.  
Groenewoudseweg 1  
5621 BA Eindhoven  
PAYS-BAS

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Charger for rechargeable batteries

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## Charger for rechargeable batteries

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The present invention relates to a method of charging a rechargeable unit, such as a rechargeable battery or a rechargeable battery pack.

The present invention also relates to a charger for charging a rechargeable unit, such as rechargeable battery or a rechargeable battery pack, said charger comprising a  
5 supply unit for supplying charging current to a rechargeable unit.

Rechargeable batteries and rechargeable battery packs have a wide spread use in the modern life. Many apparatuses, such as mobile phones, battery operated electric  
10 shavers, battery powered vehicles, electrical tools etc, are equipped with such batteries.

The rechargeable batteries and battery packs need to be recharged every now and then. There are several types of chargers that can be used for recharging rechargeable batteries. A common type of charger employs a constant current level (CC) throughout the whole charging of the battery. Fast chargers of this type employ a high, constant current until  
15 the battery is fully charged. An electronic unit in the charger is used to detect end-of-charge and cut off the charging current.

The above-mentioned CC-charger is useful for charging e.g. NiCd (Nickel-Cadmium) and NiMH (Nickel-Metal-Hydride) batteries. With these batteries the end-of-charge state can be detected as a sudden increase in the temperature of the battery and as a  
20 drop in the terminal voltage of the battery.

Lithium batteries (including lithium-ion, lithium-polymer and lithium solid state batteries) cannot be charged by fast chargers of the type mentioned above, since lithium batteries do not provide the above-described indications of end-of-charge and since the maximum voltage has to be controlled to avoid damage to the lithium batteries.

25 US patent no 5,994,878 to Ostergaard et al. describes a charger that can handle different types of batteries, including lithium batteries. The charger may first charge the battery in a constant current mode and then in a constant voltage mode (constant current then constant voltage charging = CCCV). During the first phase of the charging process the charger is in a constant charging current control mode. The charging current is controlled at a

preset level and the charging voltage is monitored. When the charging voltage reaches a certain, preset level the charging process enters a constant charging voltage control mode. In this mode the charging voltage is held substantially constant while the charging current is reduced. The charging as described in US 5,994,878 is however slow and will not allow the quick charging of a battery.

An object of the present invention is to provide a charging method that makes it possible to quickly add capacity to rechargeable units.

10 A further object of the invention is to provide a charger that makes it possible to quickly add capacity to rechargeable units.

A charging method according to the preamble is characterized in that a charging current corresponding to more than 2 C-rates is supplied to the rechargeable unit, and

15 that the supply of charging current is interrupted before the rechargeable unit has been charged to maximum 80% of its full capacity.

It has been found that the interruption of the charging when the rechargeable unit is partially charged makes it possible to increase the charging current substantially as compared to prior art chargers without any risk of damaging the rechargeable unit. The invention thus provides for a very quick partial charging of a rechargeable unit. A typical situation where this has very material advantages is when a user just about to leave his or her home finds out that the battery of e.g. the mobile phone or the shaver is empty. By charging according to the method described above the person may in just a few minutes charging obtain sufficient battery charge for the need in e.g. a day. Another example is hybrid electrical vehicles H(EV) and in particular electrical vehicles. A user who finds the batteries of the vehicle empty may in a very short period of time charge the batteries with sufficient charge for the ride home.

20 The measure as defined in claim 2 has the advantage that a rechargeable unit may be fully charged very quickly. The first charging sequence, i.e. the charging at a current of more than 2 C-rates to maximum 80% of the full capacity, is very rapid. After this sequence has been interrupted a second sequence in the form of a normal charging is started. The normal charging is slow, but since the rechargeable unit was partially charged at a very high rate the total time to fully charge the rechargeable unit is considerably shorter than

with prior art charging methods.

The measure as defined in claim 3 has the advantage that an extremely quick, partial charging may be provided. Such charging is preferable when charging time is very limited.

5 The measure as defined in claim 4 has the advantage that a fully or almost fully charged battery or battery pack is not charged according to the invention. Thus the risk of damaging the battery is substantially eliminated.

A charger according to the preamble is characterized in that the charger further comprises

10 means for supplying a charging current of more than 2 C-rates to the rechargeable unit, and

means for interrupting the charging before the rechargeable unit has been charged to maximum 80% of its full capacity.

The charger described above will provide for a very quick partial charging of a rechargeable unit without risk of damaging said unit.

15 The measure as defined in claim 6 has the advantage that the user of the charger can choose the charging mode that suits the present situation. If the user is in a hurry he or she chooses boost charging, e.g. by pushing a corresponding button. If there is plenty of time for charging the person pushes another button to choose normal charging.

20 The measure as defined in claim 7 has the advantage that the charger may be utilized also for fast full charging of a battery. Since the normal charging, in this case charging the battery from partial to full capacity, occurs at a low C-rate the battery is not damaged during any part of the charging.

25 The measure as defined in claim 8 has the advantage that the charger provides for both partial charging and full charging. After interrupting the high rate partial charging the charger automatically shifts to slow rate normal charging to finalize the charging of a battery. The charger could thus be used both when the user quickly wants some capacity added to a battery and when the user wants to fully charge the battery. No control buttons are necessary since the user could terminate the charging at any time by just cutting off the supply of charging current, e.g. by disconnecting the shaver from the mains socket.

30 The measure as defined in claim 9 has the advantage that the user becomes aware that the fast charging is terminated and that the battery is partially charged and ready for use. The user may then choose to interrupt the charging or allow it to proceed in a normal charging mode.

The measure according to claim 10 provides a simple way of interrupting the charging. A timer function is cheap and simple to include in a control unit controlling the charging and provides a safe way of interrupting the charging well before the high charging current causes any damage to the rechargeable unit. The timer function is pedagogic in that it makes the charging method easy to use and understand for the end user.

These and other aspects of the invention will be apparent from and elucidated with reference to the embodiments described hereafter.

The invention will hereafter be described in more detail and with reference to the appended drawings.

Fig 1 is a schematic drawing of a charger according to the invention.

Fig 2 is a diagram showing the charging principles of boost charging and normal charging.

Fig 3 is a diagram showing the capacity growth of a battery during boost charging and during normal charging.

Fig 4 is a diagram showing the charging times for an empty battery at different initial charging currents and different final depths of charge.

The expression C-rate is often used when discussing the charging of batteries. 1 C-rate is the charging current that would be needed to charge an empty battery to its maximum capacity in 1 hour. For each battery capacity a certain C-rate means a certain current.

As used in the present application the expression "boost charging" means a charging method for quickly adding capacity to a battery by charging it.

As used in the present application the expression "normal charging" means a charging method for charging, at a rather slow rate, a battery to its maximum capacity.

As used in the present application the term "cycle life" refers to the number of times a battery can be recharged before it has to be disposed of. A long cycle life means that the battery can be recharged many times.

As used in the present application "depth of charge" (DoC) refers to the charged capacity of a battery or battery pack. A DoC of 100% means that the battery has

In Fig 1 a preferred embodiment of the invention in the form of a battery charger 1 is shown. The battery charger 1 has a charge current supply unit 2 adapted to supply a desired voltage and current. Terminals in the form of electrical cables 3, 4 connect the charger 1 to a battery 5 that is to be charged. Preferably the cables 3, 4 are each split up into a current lead and a sense lead for sensing the voltage. The battery charger 1 has a control unit 6 that controls the current and voltage supplied by the supply unit 2 to the battery 5. The control unit 6 is supplied with a selector comprising a first control button, schematically shown as 7 in Fig 1, for activating a normal charging of the battery 5. The selector further comprises a second control button, schematically shown as 8 in Fig 1, for activating a boost charging of the battery 5.

The normal charging is activated when the user of the charger 1 pushes the normal charging button 7. The normal charging of the battery 5 is preferably performed according to the constant current/constant voltage method (CCCV-method) or at a constant current level (CC-method) depending on the type of battery to be charged. With the CC-method the current may be supplied in pulses of substantially the same current.

With the CCCV-method, which is often employed for charging lithium batteries, the control unit 6 controls the supply unit 2 such that the battery 5 is first charged at a constant current mode (CC-mode) while monitoring the voltage (i.e. the voltage as measured between cable 3 and 4). The constant current  $I_{\text{const}}$  during the CC-mode is typically set low such that an empty battery will obtain about 50-90% of its nominal max capacity during the CC-mode. A typical constant current  $I_{\text{const}}$  for a lithium battery would be 0,7 C-rate, that is a current that, if held constant during 1 hour, would charge the battery to 70% of its maximum capacity. When the voltage after some time reaches the prescribed maximum voltage  $V_{\text{max}}$  the control unit 6 changes to a constant voltage mode (CV-mode). During the CV-mode the current supplied by the supply unit 2 is controlled such that the voltage is kept constant at  $V_{\text{max}}$  while the current is allowed to decrease. The control unit 6 stops the charging when the current has been decreased to a small value or after a predetermined time interval sufficient to make the battery fully charged. The battery thus charged to its maximum capacity in a slow and cautious manner is ready for use. The normal charging provides for a long cycle life of the battery and a fully charged battery.

With the CC-method, which is often employed for charging NiMH and NiCd batteries, a constant current level (which may mean a pulsed current) is supplied to the battery all through the charging. Charging is interrupted when a detection method indicates

that the battery is fully charged. One such detection method is temperature measurement. The temperature of the battery is measured and when it exceeds a certain temperature the battery is fully charged. Another detection method is measurement of voltage change over time ( $dV/dt$ ). When a voltage decrease is detected the battery is fully charged and charging is interrupted. The constant charging current during this type of charging of a NiMH battery is as a maximum about 1 C-rate, since a higher charging current may cause oxygen formation in the battery followed by an increased gas pressure. NiCd batteries are charged at maximum 2 C-rates for the same reason. RAM batteries are charged at charging currents below 1 C-rate.

The boost charging of the battery 5 is activated when the user of the charger 1 pushes the boost charging button 8. The boost charging of the battery 5 is performed according to the method of the present invention.

With boost charging of lithium batteries the control unit 6 controls the supply unit 2 such that a very high initial current  $I_{init}$  is immediately supplied to the battery 5. The control unit 6 monitors the voltage supplied (i.e. the voltage as measured between cable 3 and 4) and controls the current such that the voltage is kept at the prescribed maximum voltage  $V_{max}$ . The initial current  $I_{init}$  is chosen such that the maximum voltage  $V_{max}$  is reached almost immediately. The control unit 6 will thus control the current supplied to the battery 5 such that the current immediately or after a very short period of time is decreased from  $I_{init}$  to a lower value. If  $I_{init}$  is very high there will be no constant current phase at all. At a somewhat lower  $I_{init}$ , still being very high in relation to the current  $I_{const}$  supplied during the CC-mode of the normal charging, there may be a short period of time before the current is decreased. In either case there is no constant current phase of the type described in relation to the normal charging.

It has been found that the initial charging current  $I_{init}$  at boost charging of lithium batteries should be higher than 1 C-rate, i.e. a current that, if held constant, would charge an empty battery to 50% of its maximum capacity in less than 30 minutes, to provide quick charging. Initial currents  $I_{init}$  of higher than 2 C-rates, still more preferably higher than 3,5 C-rates, have been found to provide a substantial further reduction of the charging time. It has been found that the initial charging current  $I_{init}$  should be chosen such that, at the start of charging, the predetermined maximum charging voltage is reached in not more than 2 minutes, since the charging at the first minutes should be performed at as high a voltage as possible to decrease the charging time. It has also been found that the initial charging



in not more than 30 seconds and still more preferably in not more than 5 seconds to provide a further substantial reduction of the charging time, the charging during the first minute being the most efficient if performed at a high current and maximum voltage, still without substantial detrimental effects on the cycle life.

5               With other types of batteries, such as NiMH and NiCd, the boost charging is preferably performed at a constant current level, which could be a pulsing current or a truly constant current. The charging current is higher than what is allowed in normal charging due to the fact that boost charging is a partial charging. The current at boost charging of NiCd and NiMH batteries is more than 2 C-rates and more preferably more than 4 C-rates.

10              It has been found that the boost charging should be interrupted when the battery 5 has been charged to maximum 80% of its maximum capacity (i.e. 80% DoC) to provide a quick charging without substantial negative effects on the cycle life. At very high charging currents, such as charging currents corresponding to 8 C-rates and higher, the charging is preferably interrupted at a DoC of maximum 60% to avoid damage to the battery,  
15              such as excessive generation of heat or gas in the battery. Such charging would provide a very quick adding of capacity to the battery and could be used when the user only has few minutes available. It has further been found that an interruption of the charging at a battery DoC of 10-60% provides a relation between time of charging and charged capacity that is attractive for most users of the boost charging function. Thus the boost charging is preferably  
20              used for quick, partial charging of the battery. To stop the boost charging at the proper time for partial charging it is preferable to include in the control unit 6 a function for measuring the DoC, i.e. the DoC of the battery at a certain time. The measurement of DoC can be made by measuring battery parameters according to one of several methods that are well known to the skilled man. Examples of such methods of measuring a battery parameter for relating it to  
25              the DoC of a battery include open circuit voltage (OCV) measurement and resistance free voltage (RFV) measurement.

              The application of boost charging is preferably restricted such that a battery that already has full capacity or almost full capacity cannot be subjected to a boost charging. The control unit 6 thus preferably includes a function for measuring the DoC, i.e. the initial  
30              DoC, of a presumably empty battery 5 before any charging, and in particular any boost charging, may start. The measurement of DoC of a battery before starting the charging thereof may be made by one of several methods that are well known to the skilled man. Examples of such methods of measuring a battery parameter for relating it to the DoC of a battery includes open circuit voltage (OCV) measurement, resistance free voltage (RFV)

measurement and battery voltage after relaxation ( $V_{\text{relax}}$ ). When charging lithium batteries it is also possible to measure the DoC at the very beginning of the charging by measuring the time before the charging current starts to decrease, provided that the initial current  $I_{\text{init}}$  is chosen such that there is short period of time before the current needs to be decreased to avoid exceeding the maximum charge voltage. The shorter the time before the charging current is decreased the higher the initial DoC. Another alternative available when charging lithium batteries is to measure the slope of the voltage increase over time when starting the boost charging, i.e. measure  $dV/dt$ . A large  $dV/dt$  then indicate a high initial DoC of the battery. If measurement of the time before charging current decreases or of the  $dV/dt$  reveals that the battery already has a high or full capacity boost charging is immediately interrupted.

In addition to the detrimental effect on the cycle life the time gained by boost charging at a high initial DoC is so low that it is preferably avoided. Boost charging should not be started, or, if at an early phase, immediately stopped, if the battery is found to have an initial DoC of more than 70% to avoid detrimental effects on the cycle life. The charger 1 may be equipped with a function, such as a flashing light or a sound, for indicating that boost charging is interrupted due to high initial DoC thus showing the user that the battery already has a certain charge. It has further been found that the relation between time of charging and charged capacity decreases the advantages of starting a boost charging at an initial DoC of more than 50%.

A further example of controlling the charging is to provide a timer function in the control unit 6. The timer is set to allow boost charging during a certain time, e.g. 5 or 10 minutes, and then interrupt the charging. The timer may be combined with the above described function for avoiding charging at high initial DoC and/or the function for interrupting charging at a certain, predetermined, DoC. The timer function makes the boost charging function easy to use and understand for the end user.

The control unit may also be adopted to allow boost charging for some time and then switch to normal charging. In such a case the battery is first charged at a high rate for a certain time or to a certain DoC. The charger then switches to normal charging and allows the charging of the battery to proceed at a low rate until the battery is fully charged.

Preferably an indication, such as the switching on of a light, e.g. a LED, or the sounding of a speaker, is used to indicate that the boost charging is finalized. The user may then choose to interrupt the charging or to allow it to proceed in the normal charging mode for fully

Boost charging may be applied to all types of rechargeable batteries. Examples of such batteries include nickel metal hydride batteries (NiMH), nickel cadmium batteries (NiCd), lead acid batteries (Pb-acid), rechargeable alkaline manganese batteries (RAM) and lithium batteries. The boost charging has been found to be particularly advantageous for lithium batteries, including lithium ion batteries (Li-ion), lithium polymer batteries (Li-polymer), lithium polymer gel batteries (Li-polymer gel) and lithium-metal batteries (Li-metal), since lithium batteries must not be charged at high voltages. Due to this fact there has previously not existed any chargers for quick charging of lithium batteries.

The charger according to the invention may be a stand-alone charger or an integral charger. Thus the charger may be an integral part of any electronic or battery driven equipment. Examples of such electronic equipment incorporating a charger are shavers, mobile phones, battery packs, electrical vehicles, hybrid electrical vehicles H(EV), and personal computers. In the case of integral chargers a selector is preferably located at the shell of the apparatus, such as a shaver, to allow the user to choose the charging mode.

A number of tests were performed to demonstrate the effectiveness of the charger according to the invention. In the tests a Li-ion battery in the form of a standard Sony US18500 cell with a nominal capacity of 1100 mAh was used. All tests were performed at 25°C.

Fig 2 shows the procedures of the boost charging and of the normal charging. The left vertical axis of Fig 2 is the charge current  $I_{\text{charge}}$  in Amperes, the right vertical axis is the charging voltage  $V_{\text{charge}}$  in Volts and the horizontal axis is the charged battery capacity in mAh. The normal charging (dotted lines in Fig 2) proceeds at a constant current  $I_{\text{const}}$  of about 1 A until the battery has obtained about 80% of its maximum capacity. The control unit 6 comprises a charge current limiting function which increases the charge current from zero to the predetermined constant charging current  $I_{\text{const}}$  and then prevents the charging current from increasing any further. During this phase of constant current (CC) charging the charging voltage increases slowly from 3,6 to 4,2 V, which is the maximum charging voltage of this cell. When the charging voltage reaches 4.2 V the charger switches to constant voltage mode. Thus the cell is charged with the last 20% of its capacity at a constant voltage of 4,2 V and a decreasing current.

The boost charging is illustrated with solid lines in Fig 2. At the start of boost charging an initial current  $I_{\text{init}}$  of 8 A is supplied to the cell. The charge voltage increases immediately, i.e. in less than 1 second, to the maximum charge voltage of 4,2 V. The control

unit decreases the charging current such that the charging voltage is maintained at 4,2 V. The charging current first decreases rapidly, within 1 minute, to about 4 A. The charging current then decreases further at a slower rate.

As is indicated in Fig 2 the charging at the end of the charging procedure, i.e. the charging of the final 20% of the charging capacity is similar for the normal charging and the boost charging. Thus it can be concluded that the impact of the high initial charging current on the charge build up is small.

In Fig 3 the capacity build up as a function of time is shown. The vertical axis is the charged capacity, i.e. the capacity added to the battery during charging, in mAh and the horizontal axis is the time in minutes. The maximum charging voltage was 4,2 V. The dotted line describes the build up of charge in an empty battery using normal charging. After 10 minutes charging using normal charging the DoC of the battery has increased to about 16% of its maximum capacity. The constant current during the 10 minutes of normal charging was about 1 A corresponding to  $1\text{A}/1100\text{mAh} = 0,9$  C-rates. Three tests were made with boost charging using an initial current  $I_{\text{init}}$  of 8 A corresponding to an initial C-rate of  $8\text{A}/1100\text{mAh} = 7,3$  C-rates. The results of boost charging of an empty battery (0% initial DoC) and batteries with 10 and 25% initial DoC are shown with solid lines in Fig 3. The empty battery obtained almost 50% of its maximum capacity after only 10 minutes of boost charging. The batteries that had an initial DoC of 10% and 25% respectively showed a somewhat slower capacity build up compared to the charging of the empty battery. However, as shown in Fig 3, the capacity build up at boost charging was in all cases considerably quicker than capacity build up at normal charging.

In Fig 4 the impact of the initial charging current  $I_{\text{init}}$  on the charging of an empty battery (0% initial DoC) to a certain DoC is demonstrated. The vertical axis is the initial charging current  $I_{\text{init}}$  in Amperes and the horizontal axis is the charging time in minutes. The curves denote the different DoC, 10-50%, at which charging is interrupted. Thus the 30% curve represents the time to charge an empty battery to a DoC of 30% of its maximum capacity at different initial currents  $I_{\text{init}}$ . The point P represents, as an example, that, at an initial current  $I_{\text{init}}$  of 3 A, a DoC of 30% is reached after 6,9 minutes.

It is evident from Fig 4 that an initial charging current  $I_{\text{init}}$  above 4 A, corresponding to an initial C-rate of about 3,6 C-rates, does not further decrease the time required to obtain a certain DoC. On the other hand an initial charging current below 3 A,

corresponding to an initial C-rate of about 1,8 C-rates, results in a substantial increase of the time required to obtain a certain DoC.

A test was performed at a maximum charging voltage higher than the allowed 4,2 V. The maximum charging voltage was thus set to 4,3 V. It was found that an empty  
5 battery (0% initial DoC) was charged to a DoC of almost 50% at an initial charging current  $I_{init}$  of 8 A in 8 minutes which is two minutes less than the 10 minutes required at 4,2 V (see Fig 3).

Finally, to summarize, a battery charger 1 for charging rechargeable batteries 5  
and/or battery packs is disclosed. Preferably the charger 1 can apply two modes of charging a  
10 battery. In a normal charging mode a battery is charged to full capacity at a relatively low rate. In a boost charging mode the battery is charged very rapidly and only to maximum 80% of its full capacity. The boost-charging mode makes it possible to provide some charge to the battery 5 when the time available for charging is limited. Due to the partial charging a much  
higher charging current than allowed at normal charging may be applied during boost.  
15 charging.

## CLAIMS:

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1. A method of charging a rechargeable unit, such as a rechargeable battery or a rechargeable battery pack, characterized in  
that a charging current corresponding to more than 2 C-rates is supplied to the rechargeable unit, and

5 that the supply of charging current is interrupted before the rechargeable unit has been charged to maximum 80% of its full capacity.

2. A method according to claim 1, wherein said charging is followed by a normal charging proceeding at a current corresponding to maximum 1 C-rate until the rechargeable  
10 unit is substantially fully charged.

3. A method according to any one of claims 1 and 2, wherein a charging current of more than 4 C-rates is used for charging a rechargeable unit comprising a NiCd or a NiMH battery.  
15

4. A method according to any one of the preceding claims, wherein a measurement of the initial capacity of the rechargeable unit is made before charging starts or at the beginning of the charging, the supply of charging current being stopped if the initial capacity is found to be higher than a predetermined initial capacity.  
20

5. A charger for charging a rechargeable unit, such as a rechargeable battery or a rechargeable battery pack, comprises a supply unit for supplying charging current to a rechargeable unit, characterized in that the charger further comprises  
means for supplying a charging current of more than 2 C-rates to the  
25 rechargeable unit, and  
means for interrupting the charging before the rechargeable unit has been charged to maximum 80% of its full capacity.

6. A charger according to claim 5, wherein the charger further comprises a manual selector for choosing between

a boost charging mode wherein the rechargeable unit is charged to maximum 80% of its maximum capacity at a current corresponding to more than 2 C-rates, and

5 a normal charging mode wherein the rechargeable unit is fully charged at a current corresponding to maximum 1 C-rate.

7. A charger according to claim 6, wherein the charger comprises means for switching from the boost charging mode to the normal charging mode when the rechargeable  
10 unit has been charged to maximum 80% of its full capacity.

8. A charger according to claim 5, wherein the charger comprises means for automatically switching to a normal charging mode for charging the rechargeable unit to full capacity at a current corresponding to maximum 1 C-rate after said interrupting of said  
15 charging.

9. A charger according to any one of the claims 5 to 8, wherein the charger comprises means, such as an LED or a speaker, for providing an indication to the user of the charger that said interrupting of said charging has occurred.

20

10. A charger according to claim 5, wherein the charger comprises a timer unit, the timer unit being devised to interrupt said charging after a predetermined time interval.

## ABSTRACT:

A battery charger (1) for charging rechargeable batteries (5) and/or battery packs is disclosed. Preferably the charger (1) can apply two modes of charging a battery. In a normal charging mode a battery is charged to full capacity at a relatively low rate. In a boost charging mode the battery is charged very rapidly and only to maximum 80% of its full capacity. The boost-charging mode makes it possible to provide some charge to the battery (5) when the time available for charging is limited. Due to the partial charging a much higher charging current than allowed at normal charging may be applied during boost charging.

Fig 1

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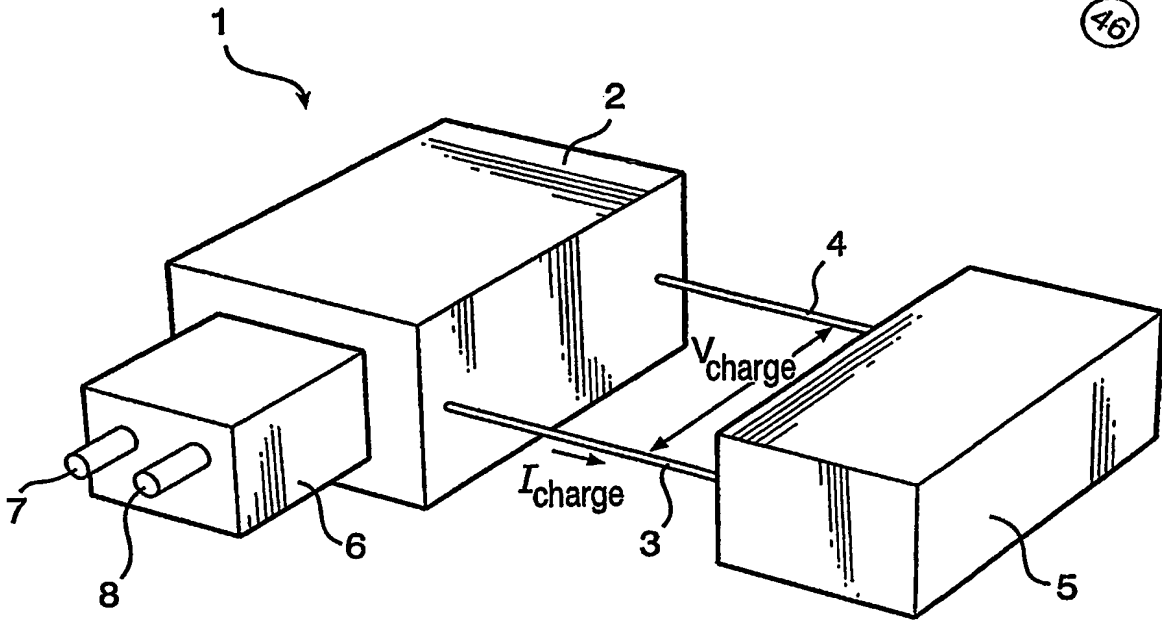


FIG.1

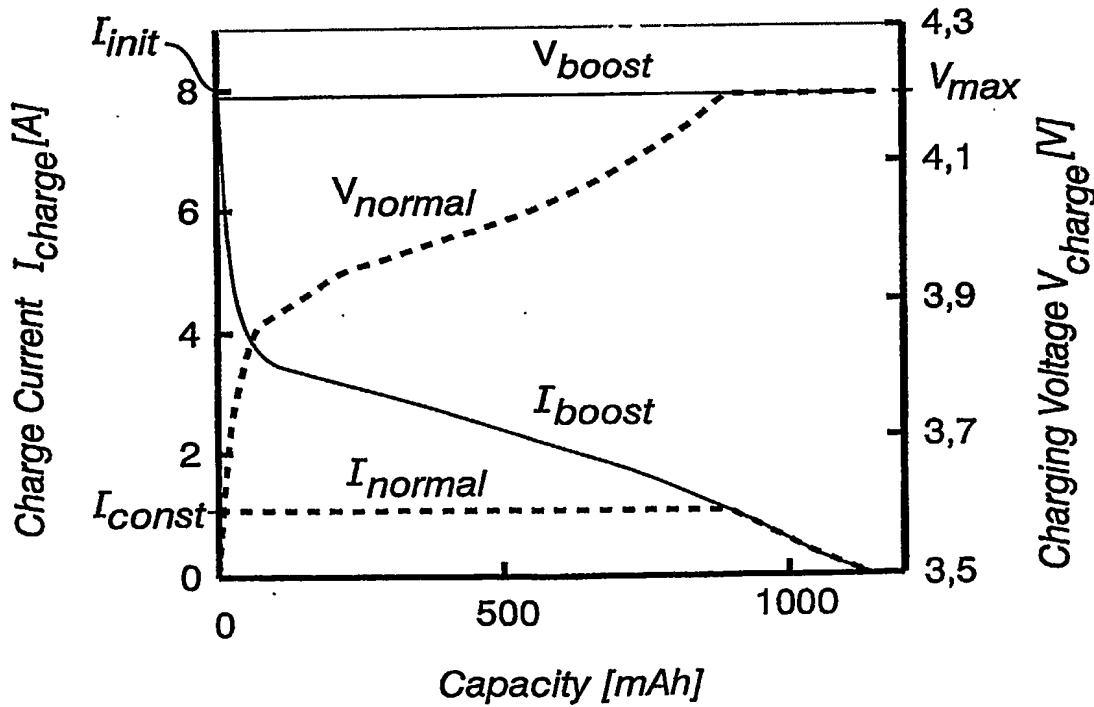


FIG.2

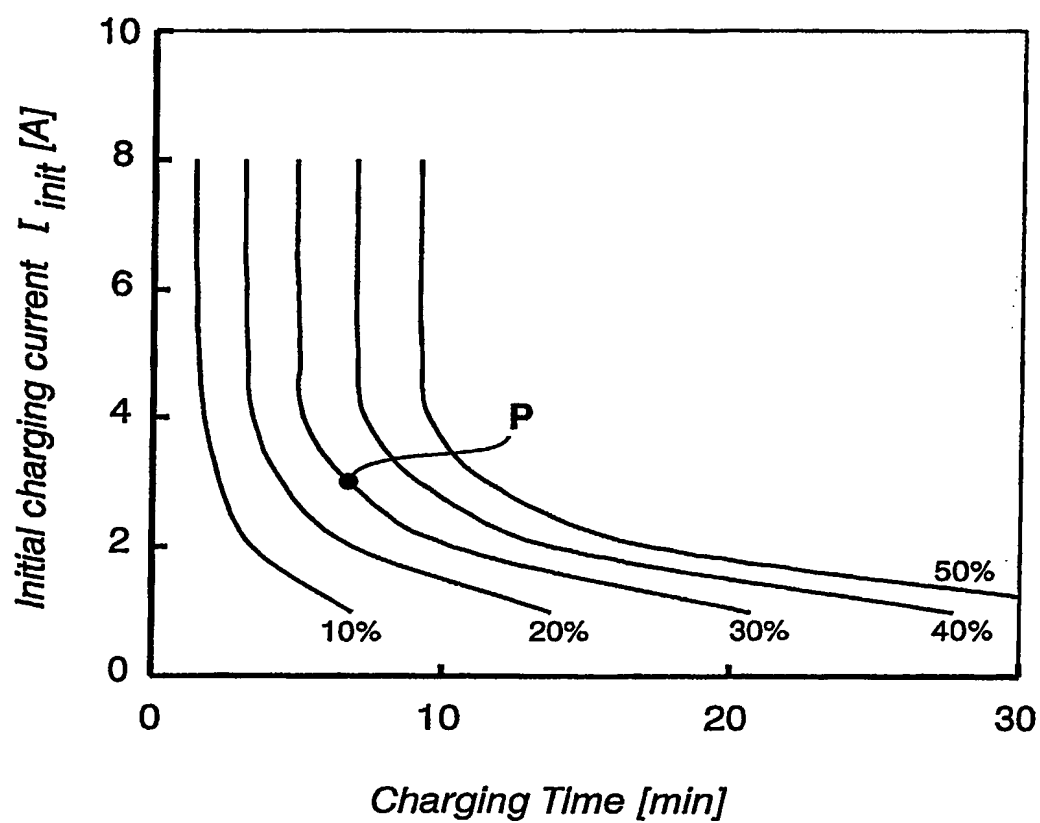


FIG.4